HIGHWAY RESEARCH REPORT

PATCHING AND GROUTING MATERIALS FOR PORTLAND CEMENT CONCRETE

FINAL REPORT

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

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STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY

RONALD REAGAN, Governor

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M&R No. 635148-B
HPR No. D03-17
Subproject No. 7

Mr. R. J. Datel
State Highway Engineer

Dear Sir:

Submitted herewith is the final report for Subproject 7 of project "Highway Concrete Problems" titled:

PATCHING AND GROUTING MATERIALS

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Report by Carl R. Sundquist and Bennett T. Squires.

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Attachment

REFERENCE: Sundquist, C. R., and Squires, B. T. "Patching and Grouting Materials", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Final Research Report 635148, Subproject 7, January, 1972

ABSTRACT: This report covers work done on evaluation of 19 commercial products sold as portland cement concrete patching compounds compared with Type III cement mortar. These products had fast setting and early strength gain characteristics. The properties tested included set time (initial and final), expansion when soaked for 24 hours, drying shrinkage, percent chlorides, percent sulfate, abrasion resistance, and compressive strength at 1 hour, 4 hours, 1 day, 3 days, and 28 days. Several compounds were tested for corrosion properties when used in contact with reinforcing steel. In addition, 15 of the products were placed in a field installation in the wheel path in the heavily traveled lane where they were subjected to freezing-thawing, snow, tire chain traffic, and summer traffic. This field installation was evaluated after one year of service.

Some of the materials were used for grouting steel into concrete. The grouting tests tried did not produce the definitive data hoped for and was abandoned early in the project.

KEY WORDS: Patching, compounds, portland cement concrete, compressive strength, corrosion, drying shrinkage, durability, high early strength cement, expansion, chlorides, sulfates, set time

ACKNOWLEDGMENTS

The authors wish to thank the many suppliers and manufacturers who submitted their products to be used in this research project. Since the State of California does not endorse any proprietary product, the identities of the various compounds have been coded.

We also would like to acknowledge the assistance provided by the assistant engineers and engineering technicians in the Concrete Research Section, especially Mr. Philip L. Young, and the Bridge Maintenance Crew of District 03.

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The opinions and conclusions expressed in this report are those of the investigators and are not necessarily those of the Federal Highway Administration.

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Compound	Brand Name
A	Speed Crete
B	Express Repair
C	Fast Krete
D	Epoxon 105
E	Epoxon 605 (aggregate)
F	Fast Fix
G	Pour Stone
H	Fix-A-Crete
I	Jet Set
J	Thorite
K	All Crete
L	Regulated Set Cement (Lone Star) (40% Regular Set Cement, 60% Sand) and 3/8" max. aggregate - 8 sacks per cubic yard mix
M	Epoxon with Regulated Set Cement
N	Five Star Highway Patch
O	Custom Plug
P	Type III Cement Mortar
Q	Rockite
R	Sak-Crete
S	Mari-Crete
T	Five Star Grout

PATCHING AND GROUTING MATERIALS

Introduction

In any extensive concrete works, there is often a need for a product for making quick repairs of a minor structural nature. There are numerous commercial products available, many of which are designed to have certain unique properties. The common properties all such products should possess are (1) rapid strength gain, (2) low shrinkage, (3) durability, (4) economy, and (5) noncorrosive to steel when used in reinforced concrete. While the quantities of such materials required is normally quite small, the importance of obtaining a satisfactory job is great especially to construction and maintenance forces.

This project was set up in 1967 as Subproject 7, "Patching and Grouting Materials" of the active FHWA research project entitled "Research of Highway Concrete Problems." The primary objective was to evaluate many of the patching and grouting products on the market. This evaluation included set time, compressive strength, bond to concrete, abrasion resistance, expansion and shrinkage, chemical analysis, and in some cases, corrosiveness to reinforcing steel.

A secondary objective of this project was to develop a test procedure to be used for accepting or rejecting products proposed for use as patching or grouting materials.

The testing of patching compounds consisted of two phases; laboratory testing and placing the products in a field installation near Blue Canyon Undercrossing on Interstate 80, where they would be subjected to severe climatic and traffic conditions.

TESTING PROGRAM

Laboratory Phase

Patching compound work began by comparing Products A, B, and T, with Type II cement mortar used as a control parameter. Shrinkage tests and compressive strength tests on 2-inch mortar cubes were performed. The shrinkage bars for Products A and B were taken from the molds and zero readings taken in as little as 20 minutes after casting. Expansion in water and drying shrinkage were determined using Test Method No. Calif. 527. The compressive strength cubes were tested at ages of 1 hour, 1 day, and 7 days. Since Type II cement mortar could not be stripped from the molds for at least one day, its use as a control was discontinued. The test results on Product B and Product A were quite similar.

Following this work on patching compounds, work began on developing a method for testing the ability of fast setting compounds to anchor steel in mature concrete. Concrete cylinders 6" high by 6" in diameter were cast and after 28 days, holes 1-5/8" in diameter were drilled through them. One-inch stainless steel bars were grouted into the 1-5/8" diameter holes using Product A, Product B, and Type II cement mortar. Fourteen days later the bars were pushed out using a testing machine. The system yielded twice; first when the mortar failed along the steel, and finally when the concrete cylinder broke. The two types of failure occurred at loads of 9000 lbs. and 16,500 lbs. using Product A as a grout; 11,000 and 17,400 lbs. using Product B; and 6800 lbs. and 17,300 lbs. using Type II cement mortar. Results of pull-out testing using Product T to anchor a 1-inch threaded steel rod in the same type cylinders did not break the concrete although the system also showed two yield points. Tests on Product T three days old yielded at average loads of 2400 lbs. and 5900 lbs., and 7-day old yielded at 5300 lbs. and 6850 lbs. (See Table 1.)

To avoid eccentric loading in the pull-out test, the bolt must be grouted straight into the hole, all holes have to be similar in size and direction, the grout must be uniformly applied into the cavity. The bolt must be held in the same position relative

Table 1

Load Developed in Grouting Tests

Product Used to Grout 1-in. Steel Bar Into 1-5/8-in. Hole	Load at Yield Point, (Lbs.)	Load at Failure, (Lbs.)	Remarks
Product A	9,000	16,500	Push out test. Age 14 days
Product B	11,000	17,400	Push out test. Age 14 days
Type II Cement Mortar	6,800	17,300	Push out test. Age 14 days
Product T	2,400	5,900	Pull out test. Age 3 days
Product T	5,300	6,850	Pull out test, Age 7 days

to the circumference of the hole.

Later, a wide selection of patching and grouting materials were obtained for use in a series of comparative tests. The following testing outline was used for this work:

1. Have a chemical analysis made. If the results show a significant amount of sulfates or chlorides, submit a sample of pulverized hardened material for further analysis.

2. Estimate the set time with Gillmore needle.

3. Run expansion and drying shrinkage tests on 1"x1"x11-1/4" bars using one day for expansion in water and drying shrinkage determined after 4 days and 7 days of drying.

4. Make 5 sets of 2" compressive strength cubes to be tested at 1 hour, 4 hours, 24 hours, 72 hours, and 28 days. Store the cubes in the fog room until time for breaking, but place the 28-day compressive cubes in water at least 7 days prior to testing. Order of priority used: (1) 1 hour, (2) 24 hours, (3) 28 days, (4) 72 hours, (5) 4 hours, except that a 4-hour test should be first priority if the cubes cannot be removed from the molds for the 1-hour test.

5. Run abrasion test on 4"x2" cylinders at an age of 3 days. Weigh the specimens after 20 seconds abrasion, 1 minute and 3 minutes total time, in the abrasion tester.

6. If the tests of drying shrinkage, compressive strength, and chemical analysis show the product to be satisfactory, it would be used for grouting a steel rod into a hole cored in concrete to make a pull-out test.

Bond tests consisted of cementing two 7"x3-1/2"x1-1/2" mortar blocks together in a crossed position so that the bonded face was 3-1/2" x 3-1/2".

A device was built to test the bond between these blocks by vertical loading. Due to many factors, this test is not very reproducible.

Samples of 20 cement products represented as "fast setting" were accumulated and subjected to the foregoing series of tests with the exception of the bond and pull-out tests just discussed. Shown in Table 2 are complete results of laboratory testing performed to establish relationships between the behaviors of the various compounds. Product P is a Type III cement mortar which was used for control purposes.

Table 2

Physical Properties of Patching and Grouting Compounds

Compound	Set Time (Minutes) Init.	Final	% Expan. 1 Day	% Shrinkage 4 Da.*	7 Da.*	% Cl	% SO_4	3 Minute Abrasion Loss, (Grams)	Compressive Strength (psi) 1 Hr.	4 Hr.	1 Da.	3 Da.	28 Da.
A	12	20	.029	.146	.198	.005	10.2	15	175	300	2470	3200	5000
B	12	30	.027	.119	.172	0	10.5	16	165	175	1400	2650	4100
C	35	125	.000	.063	.080	.04	2.9	26	20	35	1040	1100	2200
D	225	445	.041	.157	.178	0	1.0	24	---	---	----	965	----
E	225	445	.008	.096	.104	0	1.1	21	---	---	630	1550	3700
F	5	23	.018	.033	.047	.10	52.3	16	4325	---	5900	5930	6250
G	4	11	.368	.069	.077	0	23.0	12	2550	4500	5800	5975	5500
H	220	410	.007	.081	.103	.10	1.0	18	---	---	470	1000	1775
I	6	51	.030	.153	.194	0	6.8	18	50	100	2100	3775	5700
J	6	18	.003	.162	.198	.015	1.0	16	840	850	840	2400	6300
K	145	380	.025	.150	.216	.005	4.7	21	---	5	1100	----	3825
L	35	50	.006	.043	.049	0	7.5	18	310	2650	2050	6200	----
M	60	120	.002	.046	.055	----	----	19	---	320	850	1130	2725
N	3	35	.032	.154	.184	0	0.7	18	100	120	3230	5000	6625
O	2	4	.016	.060	.088	.10	0.9	18	1550	1970	1650	2875	3550
P	110	240	.002	.083	.097	----	----	18	---	100	1775	3575	7915
Q	10	14	.011	.039	.050	.03	48.6	--	5567	5733	6040	5865	5260
R	26	60	.006	.067	.070	.03	1.0	--	---	---	4550	5030	----
S	7	110	.020	.124	.172	.01	2.9	--	---	---	3985	5840	----
T	120	195	.015	.078	----	0	----	--	---	40	4800	5920	8030

* Days of drying after 24 hours of moist curing followed by 24 hours of water immersion.

Included in the laboratory studies was some testing for corrosion potential of the materials. The test specimens were 2-1/4 x 4-1/2 x 15 inches with a 1/2-inch diameter x 19-inch long reinforcing bar set in the center of the mortar specimen with 1 inch of cover below the bottom of the bar. Half of these specimens were placed in 4 inches of a saturated salt solution and the other half were placed in 4 inches of tap water when they were 24 hours old. The products tested in the saturated salt solution were E, A, L, N, C, and P (Type III cement mortar). Products E, A, P, M, T, and F were tested in tap water. The electrical potential of the bars was measured periodically since a large jump in potential occurs when corrosion of the steel begins. After two weeks of soaking, half the specimens were broken open and the bars visually investigated for corrosion. The second half of the specimens placed in the salt solution were opened after three months of soaking and the second half of the specimens in the tap water were opened after four months of soaking. The specimens soaked in the salt solution that had corrosion after two weeks were Products E, A, L, and after three months, Products E, A, L, and N had corrosion. Of the specimens opened after soaking in tap water for two weeks, only F had corrosion, and after four months, none of the remaining specimens had corrosion. Product F was only included for the two-week test.

In addition to the corrosion tests, the pH of the materials was determined for the original powder and of pulverized powder after the material had hydrated and hardened. These pH values and corrosion test results are given in Table 3.

Field Work

In June 1969, a test section was installed in the eastbound lanes of Interstate 80 on and approximately 400 feet west of the Blue Canyon Road Undercrossing bridge. This location is at an elevation of about 5500 feet, has heavy snowfall, many freeze-thaw cycles and applications of deicing salts, and considerable chain traffic. Products A through O were used in the field tests.

The truck lane of the highway in this area has scaled considerably. Selected for patching were various holes and spalls in the concrete pavement, plus a pair of longitudinal cracks in the left wheel track of the truck lane. The cracks, holes, and spalls were chipped free of unsound concrete and blown clean with an air hose. Two holes on the bridge were patched, and

Table 3

Results of Corrosion and pH Testing on Patching Compounds

	pH			Corrosion Results**	
	Original Powder				
Compound	15 min.*	1-1/2 hrs.*	Hardened State (Pulverized)	Saturated Salt Solution	Tap Water
Product E			12.3	Corrosion in 2 wks.	No corrosion at 4 mos.
Product A	13.0	13.8	12.4	Corrosion in 2 wks.	No corrosion at 4 mos.
Product P			12.5	Spot of corrosion at 3 months	No corrosion at 4 mos.
Product L	13.0	13.5	12.3	Spot of corrosion at 2 wks.	Not tested
Product C	12.7	12.7	12.1	No corrosion at 3 mos.	Not tested
Product N	13.5	13.9	12.5	Corrosion at 3 mos.	Not tested
Product M	11.2	11.2	11.4	Not tested	No corrosion at 4 mos.
Product T	12.2	12.2	12.1	Not tested	No corrosion at 4 mos.
Product F	11.7	11.7	12.1	Not tested	Corrosion in 2 wks.

* Time after water added to powder

** Corrosion on reinforcing steel with a minimum of 7/8-inch of cover the exposed steel bars were cleaned by sandblasting. All surfaces on which patching compounds were to be placed were primed with epoxy resin adhesives. Although these adhesives can be obtained in a wide range of setting times, those which began to tack in 30 to 45 minutes after initial mixing of the components were selected.

The longitudinal cracks were patched with samples of a wide range of materials subjected to similar traffic loads. Two compounds, Product O and Product L, both low in shrinkage and corrosion potential, were placed on the bridge in the wheel track of the truck lane. Patches of Product E and Product D without fast setting properties were put along the pavement edges where their chances to set before receiving traffic were more favorable. The remainder of the fast setting compounds were used to patch cracks, spalls, and holes in the passing lane of traffic. All patches were cured with a clear paraffin based curing compound.

At the time of the last survey (April 1970), Product N and Product M were wearing the best. Project J and Product O are in slightly poorer condition, but ahead of the group which shows severe wear. Mortar containing Fair Oaks sand and Product L is wearing well in two areas and poorly in two others, while 3/8" maximum sized aggregate concrete made with Product L is wearing very poorly. These tests are rather limited and only indicate the expected performance under other conditions.

Following is an individual comment on each product used in the field test based on inspections during twelve months of exposure to traffic.

The test patches of Product D and Product E are subjected to fewer wheel crossings than all the other patches because they are along the edges of the pavement. They were so placed because closure to traffic was restricted to working hours and laboratory tests indicated that the cement in the compound does not set in less than 7 hours. Cracks in these slow setting epoxicized compounds reflect their relatively high shrinkage characteristics. The surfaces performed well under traffic for the first two months, but after the third month surface wear was evident. Product D at the end of one year, has minor edge spalling and minor cracking with surface wear beginning to show. Product E had minor cracking and edge spalling with surface wear beginning at six months and during the next six months, the cracking and spalling did not progress, but surface wear progressed to the point that the aggregate is exposed.

Both patches of Product I show considerable cracking and minor edge spalling. Wear on the surface is medium. The wear and cracking have progressed slowly over the last nine months of observation. Surface of patch near pavement edge has numerous hairline cracks, but surface is wearing well.

The surface of Product N is wearing quite well. It appears to be one of the best of the compounds placed in the wheel path. Hairline cracking is evident throughout the patch and very minor edge spalling is evident in the patch in the wheel path. No spalling has occurred in the patch near the pavement edge.

Product A has numerous minor cracks and is spalling at the edges. The surface is wearing moderately in the patch in the wheel path and is wearing well in the patch near the pavement edge. Product A mixed with a PVA (polyvinyl acetate) bonding agent product is badly worn and cracked; however, there is no edge spalling.

Product B has major cracking and moderate edge spalling, and has moderate surface wear.

Product G was placed only in the passing lane and expanded noticeably in the hole in which it was placed, and for 1-1/2 months, the surface was quite resistant to wear. After three months however, spalling and cracking appeared, and wear on the surface was evident. Care should be used in selecting this material for use since the manufacturer's literature states that this product cannot tolerate continuously wet conditions. As a check, cubes for 28-day compressive strength testing were placed in water to check for solubility over a period of time. After 4 weeks, approximately 1/8-inch all around the cube had become loose and powdery which further confirmed that this material is not resistant to constant moisture.

Project J and Product O were rated just below Product N and Product M in overall field performance. The surface of Product J is wearing fairly well - there is considerable hairline cracking and edge spalling is light.

Product O is the compound that sets in 2 to 4 minutes. It is thus difficult to place, and the two patches of this material are not wearing exactly the same. The surface is wearing well, but cracking is a problem. So far most cracks are hairline, but one patch shows a major crack. Edge spalling is light to moderate. The surface is moderately worn and has turned black. The patch of this material placed on the bridge had minor cracking and moderate edge spalling at 6 months. The area where this patch was on the bridge had been further patched between 6 months and 11 months and the patch was removed.

Product M also looks very good. The surface is wearing well and edge spalling is minor. The patch has some minor shrinkage cracks wider than the hairline variety.

Product C shows moderate edge spalling and cracking. The surface shows more wear than some of the previously described products and shows definite chain marks. This product was mixed with a PVA bonding compound and the patch of the combined compound squeezed out under traffic. The area was patched with asphalt concrete a month after placing.

Product K was represented as fast setting, but it did not harden prior to the time the lane had to be reopened to traffic. It, therefore, squeezed out due to plasticity and patching with asphaltic concrete was necessary. This is not considered a valid application for this material. It should be used where several hours can be allowed for strength gain before being loaded.

Product F set more slowly in the field than in the laboratory. It began to crack into blocks during the second month of service. At the time of the final survey, the patch made with this material had major alligator cracking, bad edge spalling and the surface is very smooth and badly worn.

A polyvinyl acetate (PVA) product was mixed with three compounds, Product A, Product K, and Product C, and placed in the field test section. The purpose of the experiment was to determine whether the glue-like PVA would help the patching compounds stay bonded to the base concrete and/or reduce its tendency to crack. These questions remain unanswered however, because the PVA retarded the set of the patching compounds and traffic squeezed the material from the areas patched with these mixed materials. An asphaltic concrete overlay was required to fill the resultant holes.

Product L was mixed with Fair Oaks sand which is a local sand of average quality. The proportions were 40% Product L and 60% sand. The resultant mortar was placed in four separate locations. Two patches show moderate wear and two are in very good condition. The two patches showing wear are in the wheel track of the truck lane in the longitudinal cracks, and one of the better patches is in the wheel track of the truck lane on the bridge. Since the last survey, this bridge has been overlayed with asphalt concrete and this patch is no longer available for observation. The second good patch is in a spalled spot in the passing lane. The two patches in the wheel path in the truck lane are somewhat different in performance. One has minor cracking and edge spalling with the sand exposed on the surface, and the other has major cracking and moderate edge spalling with sand exposed on the surface. 3/8-inch maximum sized aggregate concrete with 8 sacks of Product L per cubic yard was put alongside the mortar in each of the areas except the bridge. It, too, is not wearing well in the truck lane but is doing well in the passing lane. This suggests that perhaps Product L mortar and concrete is sensitive to water-cement ratio, conditions of placement, or other factors. A series of laboratory tests for strength and abrasion of various mixes of Product L in mortar and concrete should be performed to determine if there is an optimum mix for this product. This work should be done when Product L becomes more readily available on the market.

In addition to the field testing with patches as described, Product M was tested for use in a thin overlay. Five areas of concrete pavement approximately 2 feet long and 6 inches wide adjacent to and west of an asphalt overlay covering the westbound structure at Blue Canyon Road undercrossing were overlayed. Two of the overlays were made with Type III cement mortar and three with Product M. One overlay for each material was placed with an epoxy bonding coat, one of each on saturated surface dry pavement, and one of Product M on dry broomed concrete.

These overlay sections were placed in August 1969, in the westbound traveled lane. They are approximately 1/2-inch thick and are feathered out for the last 6 inches away from the AC overlay. Four of the overlays were cured with a wax base curing compound; the one exception being the Product M overlay placed on dry pavement.

After 5 months of traffic, these patches were surveyed and again after 9 months of service. The Type III cement mortar with epoxy tack was still in good condition after 9 months with minor chipping at the edges and a few hairline cracks; the Type III cement mortar without the epoxy tack was completely worn or chipped away before 5 months; Product M overlay with epoxy tack had very slight cracking and slight chipping at the edges, still in very good condition after 9 months; Product M on SSD pavement had no cracking, but the feathered end was chipped back about 3 inches; and Product M patch placed on dry pavement was badly chipped and had major cracking at 5 months and one corner about 8 sq.in. in a triangle was all that remained after 9 months.

CONCLUSIONS

With regard to concrete patching compounds, the research objective of developing a standard series of tests and evaluating the products currently available has been achieved. With the exception of bond to old concrete, this project has provided the necessary background to make a comparative evaluation of an unknown fast setting concrete patching compound in one week's time. Development of a reproducible test for determining the effectiveness of fast setting cement products as grouting compounds was not accomplished, especially with respect to a product's ability to grout an anchor bolt in a hole bored through concrete.

The research results are currently being implemented. When manufacturer's representatives propose field use of a material to contractors, or maintenance and construction personnel, the products can now be evaluated by this laboratory. We have recently tested three newly submitted patching compounds, Products Q, R, and S. To perform testing sufficient to compare and class an unknown product with products previously tested, requires approximately 10 man hours of work.

For a quick evaluation, the best method of distinguishing between patching compounds is by the results of shrinkage tests using California Test Method No. 527. In 7 days, fast setting compounds seem to shrink less than 0.100% or more than 0.150%. In other words, if they are going to shrink excessively, they apparently do it in the first week. Simultaneously with the shrinkage test, it is important to determine the set time, and test for chlorides and sulfates. Products high in chlorides must be eliminated because of corrosion potential, and the test for sulfates identifies products high in gypsum content which also creates corrosion potential. Products with a large percentage of gypsum usually are low in shrinkage and gain strength rapidly, so they tend to look like excellent compounds in initial testing. Cement products with high gypsum content however, are susceptible to deterioration when exposed to moisture for a period of time, and soluble sulfates remaining after hydration can cause corrosion. These tests, plus a set of compressive strength cubes tested at an age of 24 hours, are sufficient to identify an unacceptable patching compound. Acceptable products should be subjected to abrasion and more extensive strength testing, such as soaking for 28 days, to establish durability and ultimate strength characteristics.

Of the products tested in the laboratory and field for this research project, four distinguished themselves in one or more areas. Each also has one or more disadvantages. Product L, although not commercially available locally, deserves more attention. This is not a premixed product, but a fast setting cement which can be used in any concrete or mortar mix. It was tested in the laboratory with Ottawa sand and Fair Oaks sand. In field testing, Product L and Fair Oaks sand were used to make mortar and an 8-sack, 3/8-inch maximum sized aggregate concrete. The mortar was low in shrinkage and high in compressive strength, especially high (2650 psi) at 4 hours. In the field, the set time was slow enough that the material was easily placed and finished, and quick setting enough that heavy traffic crossing at the age of one hour did no evident damage. The cement is sufficiently low in corrosive salts to be safely used on bridge decks. Durability of this concrete and mortar is questionable and could probably be improved with further testing and experience with the material.

Product M is low in shrinkage, can take traffic in less than 2 hours, and has the elasticity afforded by its epoxy resin ingredients. It is low in compressive strength -- 850 psi in one day, 1150 psi in 3 days, and 2700 psi in 28 days. The one small field patch with this material at the Blue Canyon test section is probably in the best condition of all patches after the first year of wear. The surface is wearing well and the mortar has slight spalling at the edges, and there is some minor cracking.

Product O to date has been the best of the premixed patching compounds. It is comparatively low in shrinkage, especially high in early strength, and low in salt content including sulfates. Its durability in the field is good, but cracks and minor edge spalling appeared within 1-1/2 months after placement. Product O is very difficult to place as it is workable for only two to three minutes, thus only the smallest patches can be placed without using several separate lifts which gives the larger patches a jointed appearance. Using lifts also seems to encourage cracking as the larger of two patches in the field test area which was placed in three lifts has wider cracks than the smaller patch placed in one lift.

Product N has exhibited the most durable surface in the field test section. The compound is high in shrinkage and gains strength rather slowly (110 psi after 4 hours) although traffic, 3 hours after placement, did not noticeably disturb the field patches. Its strength at later ages is sufficiently high (3200 psi in one day, 5000 psi in 3 days, and 6650 psi in 28 days). The Product N field test patches show numerous hairline cracks and spalling at the edges, probably due to the high shrinkage characteristics. The compound is quite low in corrosive salts.

RECOMMENDATIONS

1. More research is needed toward the development of a reproducible test for determining the ability of grouting materials to anchor steel in concrete and to evaluate bond to old concrete. Tests attempted to date in this laboratory have yielded scattered results because the steel has not been set exactly in the direction of its removal, and no method for uniformly grouting around the steel is available. In any new test, one should be able to conveniently put a uniform amount of grout around an anchor bolt which has been chosen as standard for all such tests. The cavity from which the bolt is pushed or pulled should be constructed or drilled in line with the direction of pushing or pulling. In the case of bond to old concrete, a method should be developed which will yield reproducible result.

2. In general, premixed patching compounds are expensive. The retail cost is $12 to $20 per 100 pounds, or $240 to $400 per ton. The lack of a really outstanding patching compound in our test series suggests that we might be able to develop a superior fast setting, low shrinkage, high early strength compound, the components of which our maintenance personnel could mix on the job at a greatly reduced cost. A logical continuation would be work by the Concrete Section toward development of mortars using Lumnite cement or Type III cement as well as more experimentation with other fast setting products.

3. We have been successful in putting heavy traffic on areas patched or overlain with fast setting compounds within two hours of placement without apparent distress to the new surface. A question remains, however, whether the early beating a fresh patch must take from traffic damages the internal structure of the young mortar or concrete. A significant number of patches in our current test section show considerable cracking which indicates that perhaps the material's structural integrity began to fail quite soon after the patch was placed. It is recommended that a field test section be established on a major highway where a portland cement concrete slab must be replaced. The old

concrete can be replaced by one or more types of quick setting concrete which should be opened to traffic by the end of the working day during which it was placed. The new concrete should be cored shortly after placement and at time intervals of perhaps one month thereafter in order to check its strength gain or loss. The strength behavior of heavily travelled quick setting concrete cores can be compared with undisturbed laboratory samples of the same material at the same ages.

Examination of expansion and shrinkage data reveals that there are quick setting compounds that can nearly comply with our Type II cement specifications of .010% expansion in water and .048% shrinkage in air at 50% relative humidity when tested using Test Method No. Calif. 527. Several other compounds are grouped in a 7-day shrinkage range of .170% to .200% which values are not necessarily comparative to Test Method No. Calif. 527. It is believed that the shrinkage test performed on a newly received sample can screen potentially acceptable compounds from the less favorable type with a minimum of work. Tests for sulfates and chlorides should be done early in an analysis so that the material's corrosivity potential is known. Set time is a third useful early test. Abrasion and strength tests should follow the three preliminary tests.

4. The entire subject of patching and grouting materials is one which should receive more coordinated effort on the part of the industry. A need exists to define materials for various applications and adopt appropriate specifications and test methods. Industry effort has contributed greatly with respect to the establishment of standards for most other construction materials. An excellent example, and one that is somewhat analagous to the subject, is that of concrete admixtures. Largely through ASTM Committee C-9, producer and consumer experts have worked together to categorize and prepare specifications for various materials under ASTM Designation: C 494, "Standard Specification for Chemical Admixtures for Concrete". A great challenge exists for those concerned with patching materials to achieve similar goals.

   Before using any of these products, it is recommended that set times be noted and allowances made for temperatures in the area of use that would vary from laboratory temperatures; increased heat will usually decrease set time and decreased heat will increase set times. Limited field tests, if adequately evaluated, can provide more conclusive information regarding performance under a variety of conditions.